Chapter 23 Problem 45
Calculate the electric potential due to a tiny dipole whose dipole moment is $4.8 \times 10^{-30}$ C.m at a point $4.1 \times 10^{-9}$ m away if this point is (a) along the axis of the dipole nearer the positive charge; (b) $45^\circ$ above the axis but nearer the positive charge; (c) $45^\circ$ above the axis but nearer the negative charge. Let at $V = 0$ at $r = \infty$.

Chapter 23 Problem 59
Write the total electrostatic potential energy, $U$, for (a) four point charges and (b) five point charges. Draw a diagram defining all quantities.

Chapter 23 Problem 61
An electron starting from rest acquires 1.33 keV of kinetic energy in moving from point A to point B. (a) How much kinetic energy would a proton acquire, starting from rest at B and moving to point A? (b) Determine the ratio of their speeds at the end of their respective trajectories.

Chapter 24 Question 2
Suppose the separation of plates $d$ in a parallel-plate capacitor is not very small compared to the dimensions of the plates. Would you expect Eq. 24–2 to give an overestimate or underestimate of the true capacitance? Explain.

Solution
Underestimate. If the separation between the plates is not very small compared to the plate size, then fringing cannot be ignored and the electric field (for a given charge) will actually be smaller. The capacitance is inversely proportional to potential and, for parallel plates, also inversely proportional to the field, so the capacitance will actually be larger than that given by the formula.

Chapter 24 Question 4
When a battery is connected to a capacitor, why do the two plates acquire charges of the same magnitude? Will this be true if the two conductors are different sizes or shapes?

Solution
When a capacitor is first connected to a battery, charge flows to one plate. Because the plates are separated by an insulating material, charge cannot cross the gap. An equal amount of charge is therefore repelled from the opposite plate, leaving it with a charge that is equal and opposite to the charge on the first plate. The two conductors of a capacitor will have equal and opposite charges even if they have different sizes or shapes.
Chapter 24 Question 11
An isolated charged capacitor has horizontal plates. If a thin dielectric is inserted a short way between the plates, Fig. 24–19, will it move left or right when it is released?

Solution
The dielectric will be pulled into the capacitor by the electrostatic attractive forces between the charges on the capacitor plates and the polarized charges on the dielectric’s surface. (Note that the addition of the dielectric decreases the energy of the system.)

Chapter 24 Question 15
A dielectric is pulled out from between the plates of a capacitor which remains connected to a battery. What changes occur to the capacitance, charge on the plates, potential difference, energy stored in the capacitor, and electric field?

Solution
When the dielectric is removed, the capacitance decreases. The potential difference across the plates remains the same because the capacitor is still connected to the battery. If the potential difference remains the same and the capacitance decreases, the charge on the plates and the energy stored in the capacitor must also decrease. (Charges return to the battery.) The electric field between the plates will stay the same because the potential difference across the plates and the distance between the plates remain constant.

Chapter 24 Problem 2
How much charge flows from a 12.0-V battery when it is connected to a 12.6 μF capacitor?
Chapter 24 Problem 5
A 7.7\mu\text{F} capacitor is charged by a 125-V battery (Fig. 24–20a) and then is disconnected from the battery. When this capacitor, \( C_1 \), is then connected (Fig. 24–20b) to a second (initially uncharged) capacitor, \( C_2 \), the final voltage on each capacitor is 15V. What is the value of \( C_2 \)? [Hint: Charge is conserved.]

Chapter 24 Problem 14
Use Gauss's law to show that \( E = 0 \) inside the inner conductor of a cylindrical capacitor (see Fig. 24–6 and Example 24–2) as well as outside the outer cylinder.

Chapter 24 Problem 23
Given three capacitors, \( C_1 = 2.0\mu\text{F} \), \( C_2 = 1.5 \mu\text{F} \), and \( C_3 = 3.0 \mu\text{F} \), what arrangement of parallel and series connections with a 12-V battery will give the minimum voltage drop across the 2.0 \mu\text{F} capacitor? What is the minimum voltage drop?

Chapter 24 Problem 36
Two capacitors, \( C_1 = 3200 \text{pF} \) and \( C_2 = 1800 \text{pF} \), are connected in series to a 12.0-V battery. The capacitors are later disconnected from the battery and connected directly to each other, positive plate to positive plate, and negative plate to negative plate. What then will be the charge on each capacitor?

Chapter 24 Problem 44
A parallel-plate capacitor has fixed charges \( +Q \) and \( -Q \). The separation of the plates is then tripled. (a) By what factor does the energy stored in the electric field change? (b) How much work must be done to increase the separation of the plates from \( d \) to 3.0\( d \)? The area of each plate is \( A \).

Chapter 24 Problem 52
When two capacitors are connected in parallel and then connected to a battery, the total stored energy is 5.0 times greater than when they are connected in series and then connected to the same battery.
What is the ratio of the two capacitances? (Before the battery is connected in each case, the capacitors are fully discharged.)

**Chapter 24 Problem 58**
A 3500-pF air-gap capacitor is connected to a 32-V battery. If a piece of mica fills the space between the plates, how much charge will flow from the battery?

**Chapter 24 Problem 62**
Two identical capacitors are connected in parallel and each acquires a charge $Q_0$ when connected to a source of voltage $V$. The voltage source is disconnected and then a dielectric $K=3.2$ is inserted to fill the space between the plates of one of the capacitors. Determine (a) the charge now on each capacitor, and (b) the voltage now across each capacitor.
Chapter 23, Problem 45

Info Given

- Dipole moment \( \vec{p} = 4.8 \times 10^{-9} \text{ C m} \)
- Point \( d = 4.1 \times 10^{-9} \text{ m} \) away from \( \vec{p} \)
- What is \( V(d, \theta) \) for \( \theta = 0, 45, 135^\circ \)

Diagram

\[ \begin{align*}
\text{Using Polar so } (x, y) & \rightarrow (r, \theta) \\
\end{align*} \]

Solution

Formulation

We choose to convert our co-ordinate system to polar co-ordinates because that will allow easier calculation.

Recall we know that the electrostatic potential is

\[ V = V(p \cos \theta) = V(r, \theta) \]

This result is derivable if we linearly add the potential due to each charge (we can do this because the potential is a scalar).
Solution

a) For \( V(r, \theta) = V(r, D) = k \frac{p}{r^2} \cos \theta \)

\[
= \frac{(8.89 \times 10^{-9} \text{ N m}^2)}{(4.1 \times 10^{-9} \text{ m})^2} (4.8 \times 10^{-3} \text{ C m}) \cos(0)
\]

\[
= 2.6 \times 10^{-3} \text{ V}
\]

b) Similarly we can calculate

\( V(r, 45) = 1.8 \times 10^{-3} \text{ V} \)

c) And \( V(r, 135) = -1.8 \times 10^{-3} \text{ V} \)
For the electrostatic potential, recall the energy from an arrangement of 3 charges is
\[ U_3 = k \left( \frac{Q_1 Q_2}{r_{12}} + \frac{Q_1 Q_3}{r_{13}} + \frac{Q_2 Q_3}{r_{23}} \right) \]

We derived this in workshop. It is recognizable that the potential is composed of the simple scalar addition of the potential due to all the electrostatic interactions of the particle. This is to say that if a fourth (or fifth) charge is introduced to the system, it will electrostatically interact (via the Coulomb force) with all the other charges in the configuration. Therefore the energy added to the system by the new particle will simply be the potential due to each interaction (\( Q_4 \) with \( Q_1 \), \( Q_4 \) with \( Q_2 \), \( Q_4 \) with \( Q_3 \)).

Solution

a) So \[ U_4 = k \left( \frac{Q_1 Q_2}{r_{14}} \right) + \frac{Q_1 Q_3}{r_{14}} + \frac{Q_2 Q_3}{r_{24}} + \frac{Q_2 Q_4}{r_{24}} \]

b) And \[ U_5 = k \left( \frac{Q_1 Q_5}{r_{15}} + \frac{Q_2 Q_5}{r_{25}} + \frac{Q_3 Q_5}{r_{35}} + \frac{Q_4 Q_5}{r_{45}} \right) + U_4 \]
Chapter 23, Problem 67

Info Given

\[ V_E = 1.33 \text{ MeV} = 1.33 \times 10^6 \text{eV} \] for an electron from a \( \rightarrow \) b

a) \( V_{E,ba} \) for a proton?

b) Ratio of their speeds?

Solution

a) Since the change in energy is due to the potential and the charge (nothing to do with mass) the both particles can be dealt with identically. Since the proton has opposite sign on charge it must also be accelerated by an opposite sign potential but same magnitude. (Which it is because it is going backwards.) Therefore the \( V_E \) gained from the proton is also \( 1.33 \times 10^6 \text{eV} \).

b) \( V_{E, \text{electron}} = V_{E, \text{proton}} \)

\[ \Rightarrow \frac{1}{2} m e v_e^2 = \frac{1}{2} m p_r^2 \]

\[ \Rightarrow \frac{V_e}{V_p} = \sqrt{\frac{m_p}{m_e}} = \sqrt{\frac{1.67 \times 10^{-27} \text{kg}}{9.11 \times 10^{-31} \text{kg}}} = 4.28 \]

So the electron is 4.28 times faster than the proton.
Chapter 24, Problem 2

Info given

\[ V = 12.0 \, V \]
\[ C = 12.6 \times 10^{-6} \, F \]
\[ Q = ? \]

Formulation

When a potential difference is applied across the plates of a capacitor, it will make charge (in the form of electrons) want to flow opposite to the potential difference. This flow of charge is what we want to find.

Solution

Recall the capacitance of a capacitor is defined as

\[ C = \frac{Q}{V} = \epsilon_0 \frac{A}{d} \]

\[ V \cdot C = Q \]

\[ \Rightarrow Q = (12.6 \times 10^{-6} \, F) \times (12.0 \, V) = 1.51 \times 10^{-4} \, C \]
Chapter 24, Problem 5

Given
\[ C = 7.2 \ \mu F \quad (F = ?) \]
\[ V_i = 12.5 \ \text{V} \quad V_f = 15 \ \text{V} \]

Diagram
(on question sheet)

Got Formulation

to solve this problem we need to remember some facts about capacitors:

- Capacitors, when disconnected from a voltage, maintain a constant charge (Charge is conserved).
- Capacitors connected in parallel have the same voltage drop across each capacitor.
- Capacitors connected in series have the same charge. (We will not use this, because we have them in parallel.)

We shall use these facts to solve the problem.

Solution

Initially, the charge on the capacitor can be determined by \[ Q_f = CV_f \]

Finally, we have our capacitor connected in such a way we can assume a capacitance \( C \). So we can write

\[ Q_f = CV_f \]
Solution

Initially the charge on the capacitance capacitance can be determined by $Q_i = C_i V_i$.

From the conservation of charge we know that $Q_i = Q_F$ and $Q_F = \text{is the sum of the charges on } C_1 \& C_2$.

Therefore $Q_i = Q_{1F} + Q_{2F}$.

But recall we can write $Q_{1F} = C_{1F} V_{1F} = C_1 V_{1F}$.

And $Q_{2F} = C_{2F} V_{2F} = C_2 V_{2F} = C_2 V_{1F}$ (so $V_{1F} = V_{2F}$).

Recall fact 2 from previous page. Capacitance does not charge.

\[
Q_i = C_1 V_{1F} + C_2 V_{1F} = C_1 V_i
\]

\[
= V_{1F} (C_1 + C_2) = C_1 V_i
\]

\[
\Rightarrow \quad C_1 + C_2 = \frac{V_i}{V_{1F}}
\]

\[
C_2 = C_1 \left( \frac{V_i}{V_{1F}} - 1 \right)
\]

\[
C_2 = 56 \mu F
\]
Chapter 14, Problem 14

Recall we have done a problem like this for a non-conductor. The only difference is that because we have conductors there is no charge enclosed within the physical volume of the conductor. (Why is that?)

Therefore our $Q_{enc}$ for $R < R_b$ will be zero so Gauss' law yields $\vec{E} = 0$.

Similarly for the region outside the concentric cylinders the charge enclosed will be of equal magnitude (comparing on the inner and outer cylinders) but opposite sign. So once again $Q_{enc} = 0$

$\therefore \vec{E} = 0$ from Gauss' law.
Chapter 24 Problem 36

Into Given
\[ C_1 = 3200 \mu F = 3200 \times 10^{-12} F \]
\[ C_2 = 1800 \mu F = 1800 \times 10^{-12} F \]
\[ V_i = 12 V \]

Diagram

a) Initially

b) Finally

Formulation

Recall the facts from problem 5.

Solution

Charge is conserved so final charge \( Q_F = Q_i \) the initial charge.

\[ Q_i = C_0 V_i = \frac{C_1 C_2}{C_1 + C_2} V_i = 13,800 \mu C \]

\[ Q_F = \frac{C_1}{C_1 + C_2} Q_i \]

\( Q_F \) is distributed over two capacitors as \( Q_{1F} \) on capacitor \( C_1 \) and \( Q_{2F} \) on capacitor \( C_2 \).

Also \( V_F = V_{1F} = V_{2F} \) (Fact 2)

So \( Q_F = Q_{1F} + Q_{2F} \)

From \( V_{1F} = V_{2F} \) \( \Rightarrow Q_{1F} = \frac{Q_{1F}}{C_1} = \frac{2Q_i - Q_{2F}}{C_2} \)
\[ q_i = 1.8 \times 10^{-7} \text{ C} \]

Therefore \[ q_i = 2 \times 10^{-7} \text{ C} \] (\( q_i = 0 \))

Therefore \[ q_{IF} = 2 \frac{c_i}{c_i + c_L} (q_i) = 1.8 \times 10^{-7} \text{ C} \]

and \[ q_{LF} = 2q_i; -q_{IF} = 1.0 \times 10^{-7} \text{ C} \]
Chapter 24 Problem 44

Info Given/Diagram
- $-Q$
- $d$
- Area of plate $A$

This is a capacitor

a) If $d' = 3d$, what is the factor of increase in the energy stored?
b) What is the work to be done to achieve this?

Solution

a) $U_1 = \frac{Q^2}{2e_0 A} \left( \frac{1}{2} \right) = \frac{Q^2}{4e_0 A}$

And $U_4 = \frac{Q^2}{2e_0 A}$

$\therefore \frac{U_1}{U_4} = \frac{\frac{Q^2}{4e_0 A}}{\frac{Q^2}{2e_0 A}} = \frac{1}{2}\sqrt{3} = 3U_1 = U_2$

The factor of increase in energy is a third of the original energy.

b) The work done is the change in energy

$U_2 - U_1 = 3U_1 - U_1 = 2U_1 = \frac{Q^2d}{e_0 A}$
Chapter 26, Problem 52

Info Given

- \( C_1 + C_2 = C \)
- \( \frac{C_1 C_2}{C_1 + C_2} = \) unknown

- \( U_p = 5 \text{ Volts} \)

connected to a battery.

\( C_1/C_2 = ? \)

Solution

\[
U_p = \frac{1}{2} (C_1 + C_2) V^2 = \frac{1}{2} (C_1 + C_2) U_p^2
\]

\[
U_S = \frac{1}{2} (C_1 C_2) V^2 = \frac{1}{2} U_p \left( \frac{C_1 C_2}{C_1 + C_2} \right)^2
\]

Given \( U_p = 5 \text{ Volts} \)

\[
\Rightarrow \frac{1}{2} (C_1 + C_2) V^2 = \frac{5}{2} U_p \left( \frac{C_1 C_2}{C_1 + C_2} \right)
\]

\[
\Rightarrow (C_1 + C_2)^2 = 5C_1 C_2
\]

\[
\Rightarrow C_1^2 + 2C_1 C_2 + C_2^2 = 5C_1 C_2
\]

\[
\Rightarrow C_1^2 + C_2^2 - 3C_1 C_2 = 0
\]

Use the quadratic formula to find

\[
C_2 = \frac{-(-3) \pm \sqrt{(-3)^2 - 4(1)(-4)}}{2(1)}
\]

\[
= \frac{3 \pm \sqrt{9 + 4}}{2} = \frac{3 \pm \sqrt{5}}{2}
\]

\[
\Rightarrow \frac{C_2}{C_1} = \frac{3 \pm \sqrt{5}}{2}
\]
Problem 24,
Chapter 24, Problem 58

Into Given

\[ C = 3500 \mu F = 3500 \times 10^{-12} F \]
\[ V = 32 \text{V} \]
\[ \mu_{\text{mic}} = 7 \]
\[ \Delta Q = ? \]

Solution

Model the mica entering the capacitor as a dielectric.

\[ Q_i = CV \]
\[ Q_F = u.CV \]

\[ \therefore \Delta Q = (u-1)CV = (7)(3500 \times 10^{-12} F)(32 \text{V}) \]
\[ = 6.7 \times 10^{-7} \text{C} \]
Info Given

C = C₁, C₂ are connected in parallel.
Each has charge Q₀ and is connected to battery at V₀.
The voltage is disconnected.
Capacitor 2 has a dielectric inserted with k = 3.2.

a) Qₘ = ?  b) Vₘ = ?

Solution

\[ Q₁ₘ = Q₁ₘ - 2Q₀ \]

a) Recall \( Q₁ = 2Q₀ \).
\( Qₘ = Q₁ₘ + Q₂ₘ \) by conservation of charge.
Also \( V₁ₘ = V₂ₘ \) since they are in parallel.

\[ \frac{Q₁ₘ}{C₁ₘ} = \frac{Q₂ₘ}{C₂ₘ} \Rightarrow \frac{Q₂ₘ - 2Q₀}{V₀} = \frac{Q₂ₘ}{C₂ₘ} \]

Therefore \( Q₂ₘ = \frac{2Q₀}{V₀ + 1} = \frac{2}{3.2} Q₀ = 0.48Q₀ \)

and \( Q₁ₘ = 1.52Q₀ \)

b) \( V₁ₘ = \frac{Q₁ₘ}{C₁ₘ} = 0.48 \frac{Q₀}{V₀} = 0.48V₀ \)